Appendix XIV

Evaluation of California Health Data in Relation to El Niño Patterns

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Abstract

Previous research on the relationship between climate and human health has demonstrated that climate variability and, by implication, long-term climate change, can affect the incidence and distribution of weather-sensitive diseases. Understanding the relationship between climate and health is essential for identifying potential health concerns associated with climate change and devising public health responses to minimize these effects.

Investigators examined existing trends in weather and health during both normal weather and El Niño events in three geographical regions in California: Sacramento/Yolo, San Francisco/San Mateo, and Los Angeles/Orange counties. These counties include portions of three major metropolitan areas. Illness was defined by hospitalizations for several major categories of disease that were analyzed separately: viral pneumonia, cardiovascular diseases (acute myocardial infarction [MI], angina, and congestive heart failure), and stroke.

Associations between weather and health were analyzed separately by patient age. For viral pneumonia, subjects were divided into three broad age groups: 0-17, 18-55, and 56+ years. For cardiovascular diseases and stroke, two age groups, 55-69 and 70+ years, were considered. Data on hospitalizations were collected from January 1983 to June 1998. Results for viral pneumonia were analyzed for females only; those for cardiovascular diseases and stroke were examined for both genders. In the analyses, weather was averaged over 4 days to smooth short-term temporal changes in weather systems. To account for the latency period between exposure to weather and disease onset, hospitalization data were lagged 7 days after weather variables. Weather variables included temperature (maximum and minimum temperature), precipitation, sea surface temperature, and maximum temperature difference.

The study found that the weather-health associations varied by geographic region. For viral pneumonia, hospitalizations in the San Francisco and Los Angeles areas increased significantly (30%-50%) with a decrease in minimum temperature. Sacramento area hospitalizations increased significantly (25%-40%) with a decrease in maximum temperature difference. In the Sacramento area, El Niño events were associated with viral pneumonia hospitalizations, showing significant decreases for girls and increases for women. These weather-health associations were independent of season.

For cardiovascular diseases and stroke, weather variables had the strongest effect on hospitalizations in San Francisco. Changes in both maximum and minimum temperature were associated with significant increases in hospitalizations for all types of cardiovascular disease for men and women 70 years of age and older. These increases were most pronounced in men with angina and women with acute MI. Men and women aged 55 to 69 years had increased hospitalizations for congestive heart failure. The hospitalization patterns in Sacramento were

generally similar to those in San Francisco, but with weaker associations. Decreasing maximum and increasing minimum temperatures affected hospitalizations in a number of age-disease categories. In general, the health effects of temperature variables were weakest in the Los Angeles area, with fewer weather-health associations observed.

El Niño events were significantly associated with cardiovascular disease hospitalizations for both men and women in the San Francisco area. In Sacramento, El Niño events increased hospitalizations for acute MI and angina, notably in women. In Los Angeles, El Niño events had little health impact.

A single temperature variable failed to explain all the associations among viral pneumonia, cardiovacular disease, and stroke hospitalizations, and specific weather factors varied across the geographic regions. The study findings underscore the complexities of the association between climate and health effects. As we can see, a model based on either the inland region or one of the coastal regions would not be predictive of the other regions in California.

The investigation was designed to generate rather than test hypotheses about associations between weather and human health. The consistency of results across disease categories suggests some common mechanism for physiological responses to changes in the weather. Data were not available to understand differences in age groups with respect to behaviors, exposures, and other factors that influence health. Improved understanding of the mechanisms underlying these relationships is needed to assess possible public health interventions.

1. Background

It is important to differentiate among weather, climate, climate change, and climate variability. Weather is a day-to-day phenomenon determined by a number of changing variables: temperature, precipitation, humidity, wind speed, and wind direction. Climate is the average weather for a particular region over a particular time period. Climate change refers to long-term change in weather variables such as average temperature or rainfall. Climate variability refers to the natural variation around average weather and includes extreme weather patterns.

Weather is known to be associated with certain human health conditions. In the fourth century, Hippocrates said:

> Whoever would study medicine aright must learn of the following subjects. First, he must consider the effects of each of the seasons of the year and the differences between them. Secondly, he must study the warm and the cold winds, both those which are in common in every country and those peculiar to a particular locality. Lastly, the effect of water on the health must not be forgotten.

Since then, most research on weather and health has focused on the seasonality of infectious diseases. Despite the multitude of studies, it is unclear why many diseases occur seasonally. Furthermore, scientists had not, until recently, explored the impacts of weather patterns and climate variability on human health. To address these research gaps, researchers have begun to investigate the relationship between El Niño events and health.

Three national and international assessments of the potential health effects of climate variability and change — conducted by the U.S. Global Change Research Program, the U.S. National Academy of Sciences (NAS) National Research Council (NRC), and the Intergovernmental Panel on Climate Change (IPCC) — were recently published. Although the assessments differ in terms of their structure and objectives, all three reports conclude that the incidence and distribution of any disease associated with weather may change with a changing climate.

The National Assessment Report of the U.S. Global Change Research Program, *Climate Change Impacts on the United States: The Potential Consequences of Climate Variability and Change*, was completed in November 2000 (NAST, 2000). The report's health sector assessment was sponsored by the U.S. Environmental Protection Agency (EPA). Authors from both public and private sectors were selected to ensure that the assessment was scientifically balanced and represented a broad spectrum of views. The scope of this assessment was defined by four questions:

- What is the current status of the nation's health and what are current stresses on the public's health?
- How might climate variability and change exacerbate or improve existing or predicted health problems?
- What is the country's capacity to adapt to climate change?
- What gaps in scientific knowledge must be addressed to understand the possible impacts of climate variability and change on human health?

Weather and climate variability are known to be directly associated with health outcomes such as heat stroke and illness, injuries, and deaths that occur during or following extreme weather events. Other adverse health effects — such as morbidity and mortality related to air pollution and illnesses associated with water-, food-, and vector-borne microorganisms — are indirectly related to weather and climate. These health effects involve intermediate and multiple pathways, making assessments more challenging (see Figure 1). The following health outcomes were selected as focus areas for the health sector assessment: temperature-related morbidity and mortality; health effects of extreme weather events (i.e., floods, storms, tornadoes, hurricanes,

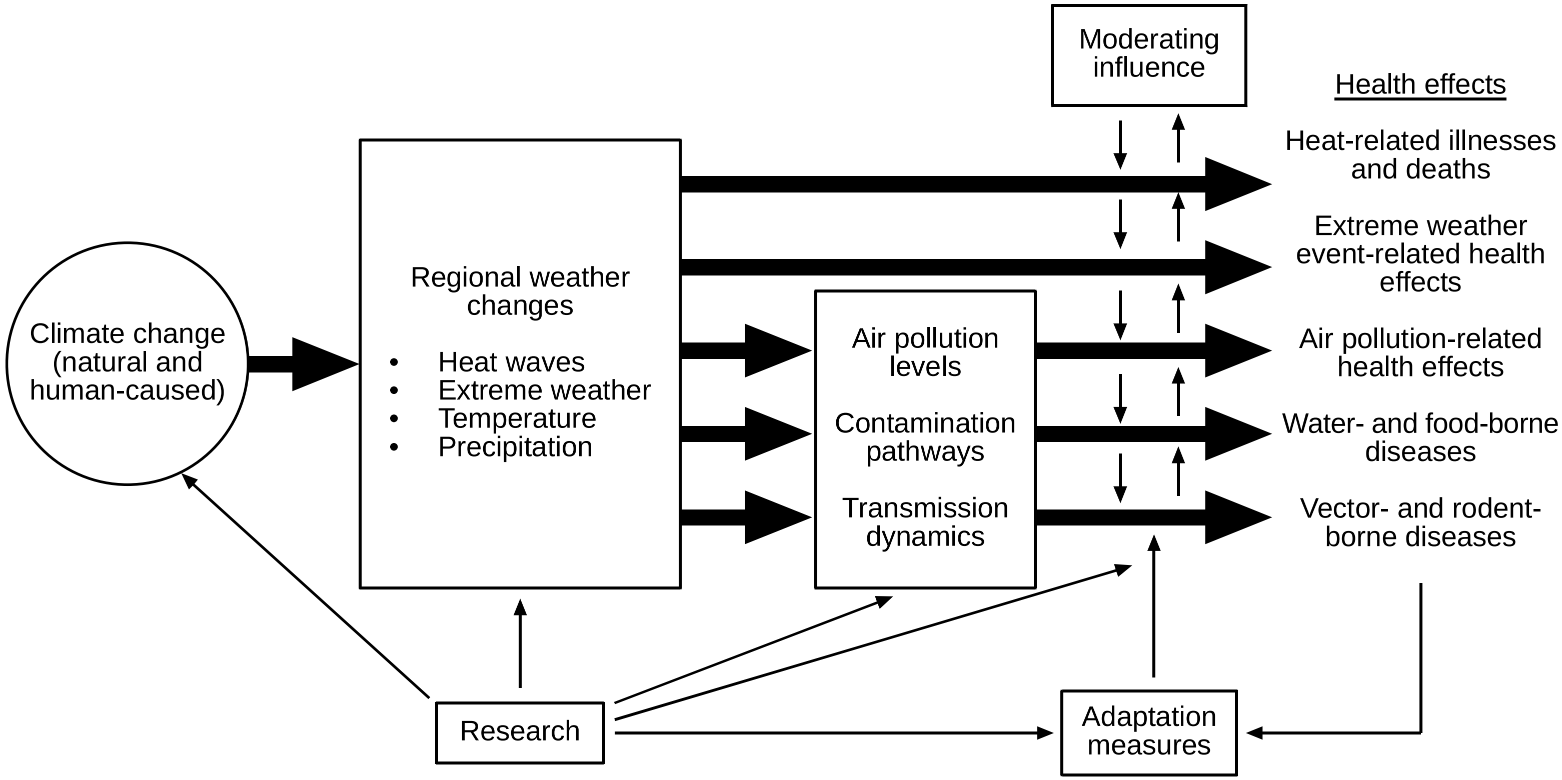


Figure 1. Potential health effects of climate variability and change

Source: Patz et al., 2000.

and precipitation extremes); health effects related to air pollution; water- and food-borne diseases; and vector- and rodent-borne diseases.

These health problems are listed in order of the relative certainty of their relationship with climate — from temperature-related mortality (most certain), to changes in vector-borne diseases (least certain). The health sector sssessment concludes that scientific knowledge about the sensitivity of human health to weather and climate is limited. Table 1 lists the key research gaps identified in the assessment.

Turning to the second assessment, a NAS/NRC committee was recently asked to address the following three tasks:

- Conduct an in-depth critical review of the linkages between temporal and spatial variations of climate and the transmission of infectious disease agents.

- Examine the potential for establishing useful health-oriented climate early-warning and surveillance systems, and for developing effective societal responses to such warnings.

- Identify future research activities to clarify and quantify possible associations among climate variability, ecosystems, and transmission of infectious disease, and identify the impacts of these factors on human health.

Table 2 presents the key finding of the NAS/NRC assessment (National Research Council, 2001).

The human health chapter (McMichael and Githeko, 2001) in the IPCC's Third Assessment Report (McCarthy et al., 2001) concluded that, overall, the negative health impacts of global climate change are anticipated to outweigh positive health impacts. Some health impacts would be caused by changes in the frequencies and intensities of extremes in heat and cold, and from floods and droughts. Other health impacts would result from the impacts of climate change on ecological and social systems, and would include changes in infectious disease occurrence, local food production and nutritional adequacy, and concentrations of local air pollutants and aeroallergens — in addition to the various health consequences of population displacement and economic disruption. For each anticipated adverse health impact, there is a range of social, institutional, technological, and behavioral adaptation options to lessen that impact. In general, the public health infrastructure needs to be strengthened and maintained. It is also crucial for nonhealth policy sectors to appreciate the many ways in which social and physical living conditions affect population health.

The chapter also concluded that there is little published evidence that, as yet, changes in population health status have actually occurred in response to the observed trends in climate in recent decades. A recurring difficulty in identifying such impacts is that most human health

Table 1. Key research gaps identified in the national assessment conducted by the U.S. Global Change Research Program

Potential health impacts	Weather factors of interest[a]	Direction of possible change in health impact	Examples of some specific adaptation strategies	Priority research areas
Heat-related illnesses and deaths	• Extreme heat • Stagnant air masses	↑	• Air conditioning • Early warning	• Improved predation, warning, and response • Urban design energy systems • Exposure assessment
Winter deaths	• Extreme cold • Snow and ice	↓		• Weather relationship to influenza and other causes of winter mortality
Extreme weather events-related health effects	• Precipitation variability (heavy rainfall events)[b]	↑	• Early warning • Engineering • Zoning and building codes	• Improved predation, warning, and response • Improved surveillance • Investigation of past impacts and effectiveness of warnings
Air-pollution-related health effects	• Temperature • Stagnant air masses	↑	• Early warning • Mass transit • Urban planning • Pollution control	• Relationship between weather and air pollution concentrations • Combined effects of temperature/humidity on air pollution • Effect of weather on vegetative emissions and allergens (e.g., pollen)
Water- and food-borne diseases	• Precipitation • Estuary water temperatures	↑	• Surveillance • Improved water systems engineering	• Improved monitoring of weather/environment on marine related diseases • Land use impacts on water quality (watershed protection) • Enhanced monitoring/mapping of fate and transport of contaminants
Vector- and rodent-borne diseases	• Temperature • Precipitation variability • Relative humidity	↑ or ↓	• Surveillance • Vector control studies	• Rapid diagnostic tests • Improved surveillance • Climate-related disease transmission dynamics

a. Based on projections provided by the National Assessment Synthesis Team. Other scenarios might yield different changes.
b. Projected change in frequency of hurricanes and tornadoes is unknown.

Table 2. Key findings from Committee on Climate, Ecosystems, Infectious Disease, and Human Health, National Research Council

Key findings: Linkages between climate and infectious diseases
• **Weather fluctuations and seasonal-to-interannual climate variability influence many infections diseases.** The characteristic geographic distributions and seasonal variations of many infectious diseases are *prima facie* evidence of linkages with weather and climate. Studies have shown that factors such as temperature, precipitation, and humidity affect the lifecycle of many disease pathogens and vectors (both directly, and indirectly through ecological changes) and thus can potentially affect the timing and intensity of disease outbreaks. However, disease incidence is also affected by factors such as sanitation and public health service, population density and demographics, land use changes, and travel patterns. The importance of climate relative to these other variables must be evaluated in the context of each situation.
• **Observational and modeling studies must be interpreted cautiously.** There have been numerous studies showing an association between climatic variations and disease incidence, but such studies are not able to fully account for the complex web of causation that underlies disease dynamics and this may not be reliable indicators of future changes. Likewise, a variety of models have been developed to simulate the effects if climatic changes on incidence of diseases such as malaria, dengue, and cholera. These models are useful heuristic tools for testing hypotheses and carrying out sensitivity analyses, but they are not necessarily intended to serve as predictive tools, and often do not include processes such as physical/biological feedbacks and human adaptation. Caution must be exercise then, in using these models to create scenarios of future incidence, and to provide a basis for early warnings and policy decisions.
• **The potential disease impacts of global climate change remain highly uncertain.** Changes in regional climate patterns caused by long-term global warming could affect the potential geographic range of many infectious diseases. However, if the climate of some regions becomes more suitable for transmission of disease agents, human behavioral adaptations and public health interventions could serve to mitigate many adverse impacts. Basic public health protections such as adequate housing and sanitation, as well as new vaccines and drugs, may limit the future distribution and impact of some infections diseases, regardless of climate-associated changes. These protections, however, depend upon maintaining strong public health programs and assuring vaccine and drug access in the poorer countries of the world.
• **Climate change may affect the evolution and emergence of infectious diseases.** Another important but highly uncertain risk of climate change are the potential impacts on the evolution and emergence of infectious disease agents. Ecosystem instabilities brought about by climate change and concurrent stresses such as land use changes, species dislocation, and increasing global travel could potentially influence the genetics of pathogenic microbes through mutation and horizontal gene transfer, and could give rise to new interactions among hosts and disease agents. Such changes may foster the emergence of new infectious disease threats.
• **There are potential pitfalls in extrapolating climate and disease relationships from one spatial/temporal scale to another.** The relationship between climate and infectious disease are often highly dependent upon local-scale parameters, and it is not always possible to extrapolate these relationships meaningfully to broader spatial scales. Likewise, disease impacts of seasonal to interannual climate variability may not always provide a useful analog for the impacts of long-term climate change. Ecological responses on the timescale of an El Niño event, for example, may be significantly different from the ecological responses and social adaptations expected under long term change. Also, long-term climate change may influence regional climate variability patters, hence limiting the predictive power of current observations.

Table 2. Key findings from Committee on Climate, Ecosystems, Infectious Disease, and Human Health, National Research Council (cont.)

Key findings: Linkages between climate and infectious diseases (cont.)
• Recent technological advances will aid efforts to improve modeling of infectious disease epidemiology. Rapid advances being made in several disparate scientific disciplines may spawn radically new techniques for modeling of infectious disease epidemiology. These include advances in sequencing of microbial genes, satellite-based remote sensing of ecological conditions, the development of geographic information system (GIS) analytical techniques, and increases in inexpensive computational power. Such technologies will make it possible to analyze the evolution and distribution of microbes and their relationship to different ecological niches, and may dramatically improve our abilities to quantify the disease impacts of climatic and ecological changes.
Key findings: The potential for disease early-warning systems
• **As our understanding of climate/disease linkages is strengthened, epidemic control strategies should aim towards complementing "surveillance and response" with "prediction and prevention."** Current strategies for controlling infectious disease epidemics depend largely on surveillance for new outbreaks followed by a rapid response to control the epidemic. In some contexts, however, climate forecasts and environmental observations could potentially be used to identify areas at high risk for disease outbreaks and thus aid efforts to limit the extent of epidemics or even prevent them from occurring. Operational disease early warning systems are not yet generally feasible, due to our limited understanding of most climate/disease relationships and limited climate forecasting capabilities. But establishing this goal will help foster the needed analytical, observational, and computational developments.
• **The potential effectiveness of disease early warning systems will depend upon the context in which they are used.** In cases where there are relatively simple, low-cost strategies available for mitigating risk of epidemics, it may be feasible to establish early warning systems based only on a general understanding of climate/disease associations. But in cases where the costs of mitigation actions are significant, a precise and accurate prediction may be necessary, requiring a more thorough mechanistic understanding of underlying climate/disease relationships. Also, the accuracy and value of climate forecasts will vary significantly depending on the disease agent and the locale. For instance, it will only be possible to issue sufficiently reliable ENSO-related disease warnings in regions where there are clear, consistent ENSO-related climate anomalies. Finally, investment in sophisticated warning systems will only be an effective use of resources if a country has the capacity to take meaningful actions in response to such warnings, and if the population is significantly vulnerable to the hazards being forecast.
• **Development of early warning systems should involve active participation of the system's end uses.** The input of stake holders such as public health officials and local policymakers is needed in the development of disease early warning systems, to help ensure that forecast information is provided in a useful manner and that effective response measures are developed. The probabilistic nature of climate forecasts must be clearly explained to the communities using these forecasts, so that response plans can be developed with realistic expectations the range of possible outcomes.

Table 2. Key findings from Committee on Climate, Ecosystems, Infectious Disease, and Human Health, National Research Council (cont.)

Recommendations for future research and surveillance
• **Research on the linkages between climate and infectious diseases must be strengthened.** In most cases, these linkages are poorly understood and research to understand the casual relationships in its infancy. Methodologically rigorous studies and analyses will likely improve our nascent understanding of these linkages and provide a stronger scientific foundation for predicting futures changes. This can best be accomplished with investigations that utilize a variety of analytical methods (including analysis of observational data, experimental manipulation studies, and computational modeling), and that examine the consistency of climate/disease relationships in different societal contexts and across a variety of temporal and spatial scales. Progress in defining climate and infectious disease linkages can be greatly aided by focused efforts to apply recent technological advances such as remote sensing of ecological changes, high-speed computational modeling, and molecular techniques to track the geographic distribution and transport of specific pathogens.
• **Further development of disease transmission models is needed to assess the risks posed by climatic and ecological changes.** The most appropriate modeling tools for studying climate/disease linkages depend upon the scientific information available. In cases where there is limited understanding of the ecology and transmission biology of a particular disease, but sufficient historical data on disease incidence and related factors, statistical-empirical models may be most useful. In cases where there are insufficient surveillance data, "first principle" mechanistic models that can integrate existing knowledge about climate/disease linkages may have the most heuristic value. Models that have useful predictive value will likely need to incorporate elements of both these approaches. Integrated assessment models can be especially useful for studying the relationships among the multiple variables that contribute to disease outbreaks, for looking at long-term trends, and for identifying gaps in our understanding.
• **Epidemiological surveillance programs should be strengthened.** The lack of high-quality epidemiological data for most diseases is a serious obstacle to improving our understanding of climate and disease linkages. These data are necessary to establish and empirical basis for assessing climate influences, for establishing a baseline against which one can detect anomalous changes, and for developing and validating models. A concerted effort, in the United States and internationally, should be made to collect long-term, spatially-resolved disease surveillance data, along with the appropriate suite of meteorological and ecological observations. Centralized, electronic databases should be developed to facilitate rapid, standardized reporting and sharing of epidemiological data among researchers.
• **Observational, experimental, and modeling activities are all highly interdependent and must progress in a coordinated fashion.** Experimental and observational studies provide data necessary for the development and testing of models: and in turn, models can provide guidance on what types of data are most needed to further our understanding. The committee encourages the establishment of research centers dedicated to fostering our meaningful interaction among the scientists involved in these different research activities through long-term collaborative studies, short-term information-sharing project, and interdisciplinary training programs. The National Center for Ecological Analysis and Syntheses provides a good model for the type of institution that would be most useful in this context.

Table 2. Key findings from Committee on Climate, Ecosystems, Infectious Disease, and Human Health, National Research Council (cont.)

Recommendations for future research and surveillance (cont.)
• **Research on climate and infectious disease linkages inherently requires interdisciplinary collaboration.** Studies that consider the disease host, the disease agent, the environment, and society as an interactive system will require more interdisciplinary collaboration among climate modelers, meteorologists, ecologists, social scientists, and a wide array of medical and publics health professionals. Encouraging such efforts requires strengthening the infrastructure within universities and funding agencies for supporting interdisciplinary research and scientific training. In addition, educational programs in the medical and public health fields need to include interdisciplinary programs that explore the environment and socioeconomic factors underlying the incidence of infections diseases.

disorders are caused by multiple factors. When estimating future health impacts, we must take into account differences in vulnerability between populations and within populations over time.

2. Introduction to EPRI Research

Scientists anticipate that climate variability may influence the distribution and incidence of weather-sensitive diseases. To investigate this possiblity, we must first understand the associations between specific health outcomes and weather variables. However — with the possible exceptions of heat stroke and certain infectious diseases — there are substantial gaps in knowledge about health-weather associations, even for frequently studied weather-sensitive diseases.

To address this issue, investigators studied the sensitivity of diseases to weather and El Niño events. El Niño/Southern Oscillation events (which include both El Niño and La Niña) are extreme cyclical weather phenomena caused by periodic changes in oceanic and atmospheric circulation patterns in the tropical Pacific Ocean. These events affect weather patterns in California. One of these extremes, El Niño, is characterized by increases in sea surface temperature (SST) and winter rain in parts of the state. Although it is uncertain whether the frequency and magnitude of El Niño events might change with global climate change, studying recent El Niño events yields information on the sensitivity of diseases to specific changes in weather patterns. These weather patterns are “natural experiments” with worldwide impacts, and research findings could have substantial public health implications. For example, they could lead to the establishment of programs for reducing and preventing disease. In this context, it is important to note that the recently acquired ability of climate scientists to predict extreme weather offers the opportunity to develop early warning systems that could notify health care providers of impending increases in disease occurrence and trigger community responses.

The objective of this research was to explore the effects of El Niño weather patterns on hospitalizations in California for viral pneumonia, cardiovascular disease, and stroke. These diseases were selected because they are known to exhibit seasonal patterns of occurrence. The investigation was designed to generate, rather than test, hypotheses about associations between weather and human health. If climate becomes increasingly variable, current modeling capabilities cannot accurately predict regional consequences for California. This study, then, does not attempt to develop quantitative predictions of potential public health impacts; its findings will, instead, provide direction for future research.

3. Description of Research Procedures

Weather and hospitalization data were collected for the period from January 1983 to June 1998 in three geographical regions in California: Sacramento/Yolo, San Francisco/San Mateo, and Los Angeles/Orange counties (referred to as Sacramento, San Francisco, and Los Angeles, respectively). Because weather patterns vary across the large San Francisco and Los Angeles metropolitan areas, only two counties in each area with similar weather were included in the analyses. To account for any latency between exposure to a factor and disease onset, weather and hospitalizations were lagged for 0, 7, 14, or 30 days. Data were summed over blocks of 4 days. Associations were evaluated with Poisson regression models, using generalized estimating equations to adjust for autocorrelation and overdispersion. The study methods included the tasks described in the sections that follow.

3.1 Acquire Weather Data and Hospital Discharge Data

California weather data were obtained from the National Climatic Data Center (NCDC) of the National Oceanic and Atmospheric Administration (NOAA) for the period from January 1983 to June 1998. Weather variables included daily minimum and maximum temperatures, daily precipitation (in 1/100 of an inch), monthly SSTs for two regions off the California coast, and the monthly Southern Oscillation Index (SOI). In addition, the viral pneumonia analyses included the maximum daily temperature difference, defined as the largest difference between the daily temperature maximum and minimum. Local SSTs are important predictors of general weather patterns in California and, as such, were used as markers of other weather variables not explicitly studied, such as wind and cloud cover. The SST data were derived from 10° quadrants of the world; one was centered on 40°N and 130°W (northern California) and the other on 30°N and 120°W (southern California). The SOI is defined as Niño Region 3.4 normalized air pressure differential. This index is used to define normal weather periods (values of -0.5 to +0.5) and El Niño events (values of less than -0.5). El Niño events were further categorized as mild (less than -0.5 to -1.5) or strong (less than -1.5). Using these criteria, there were 48 months with normal weather, 36 months with mild El Niño conditions, and 60 months with strong El Niño conditions during the study period. Forty-two months in this time period had La Niña conditions, and were excluded from the analyses.

The size of the data set required that the weather data be aggregated into larger units. Four-day averages were chosen for two reasons: to capture large weather patterns that typically take several days to move through California, and as a smoothing process to account for short-term temporal trends. In the viral pneumonia analyses, one unit of temperature change was defined as a 5°F decrease. In the analyses of cardiovascular diseases and stroke, one unit of temperature change was defined as a 3°C change (decrease for maximum temperature and increase for minimum temperature). One unit of precipitation change was defined as a 0.2 in. increase, and one unit SST change as a decrease of 1°C. (These values were approximately 1 standard deviation from the mean.) The maximum temperature difference was defined as the largest difference between the maximum and minimum temperature for one day during the 4 day period.

Associations between weather and hospitalizations were evaluated considering 0, 7, 14. and 30 day lag periods. Only the results for the 7 day lags are reported. The data were first lagged (hospitalizations on day 8 were associated with weather data on day 1) and then aggregated into 4 day blocks. Because the 4 day grouping was not excessively broad relative to the 7 day lag period, the two were largely independent of each other.

3.2 Select and Define Disease Outcomes, Design Database Queries

California's Office of Statewide Health Planning and Development supplied hospital admission data for the period from January 1983 through June 1998. Information was obtained from all nonfederal hospitals in the state. Records included data on patient demographics (age, gender, race, and zip code), date of admission, and disease diagnoses. This information was linked to weather data from NOAA stations throughout California. The analyses assumed that subjects experienced weather conditions identical to those recorded by their local weather stations.

The broad category of viral pneumonia (480-487 in the 9th revision of the International Classification of Diseases), rather than influenza, was analyzed to reduce the possibility of data missclassification. Data were also analyzed for acute myocardial infarction (MI; 410), angina (4111.1 and 413), congestive heart failure (428), and stroke (430, 431, 432, 433, 434, 435, and 436). The data were analyzed separately for males and females. For viral pneumonia, subjects were divided into three age groups: 0-17, 18-55, and 56+ years. For cardiovascular diseases and stroke, two age groups of 55-69 and 70+ years were considered. The total number of hospitalizations, rather than population rates, were analyzed. Investigators believe that the inclusion of calendar year in the analysis accounted for changes in hospitalizations over time caused by differences in population age and density.

3.3 Analyze Data and Prepare Report

The study used the statistical approach applied to air pollution and health outcomes by Morgan et al. (1988) and a collaborative European project (Katsouyanni et al., 1995). Poisson regression models that include a linear time factor to account for trends in hospital admissions over the 15.5 year period were used. The generalized estimating equations (GEE) of Zeger and Liang (1986) were applied to the data to adjust for autocorrelation and overdispersion. Autocorrelation is an important factor that must be controlled in data of this type. For example, weather conditions are often correlated from one day to the next: one sunny day is likely to be followed by another. It is unlikely, however, that hospital admissions are autocorrelated. Overdispersion may be present in count data (hospital admissions) that are assumed to follow a Poisson distribution. The goodness of fit of the models was assessed using deviance and Pearson chi-square statistics. The percent change in hospitalization per unit increase was estimated for each of the variables in the model and the corresponding 95% confidence intervals were calculated. These confidence intervals correspond to a 0.05 level of statistical signifcance.

To evaluate the impact of season on hospital admissions, sensitivity analyses were performed by including a season indicator in the main statistical models. Season was defined as winter (December, January, and February); spring (March, April, and May); summer (June, July, and August); and fall (September, October, and November). The objective of the sensitivity analyses was to compare associations with and without the season indicator in the model. Using Fisher's exact test, we found no association between season and El Niño events ($p = 0.78$), so we can conclude that including both a season indicator and an El Niño indicator in the model did not distort the results. Although the season indicator was significant, the percent change in hospital admissions resulting from weather variables, after adjusting for season, did not change substantially. The changes in hospital admissions were of similar direction and magnitude for all models with and without the season indicator. Furthermore, the predictive power of the models did not increase significantly when the season indicator was included. As a result of this analysis, the study findings are presented without adjustment for season.

We performed two sets of analyses. The first set was strata-specific, analyzing data for normal weather periods and El Niño events separately. The second set of analyses combined the normal and El Niño data sets and included an indicator that defined El Niño events as mild or strong. The purpose of this approach was to estimate the association of El Niño events with hospitalizations while controlling for other weather effects.

4. Results

4.1 Viral Pneumonia

Table 3 shows weather data for both normal weather periods and El Niño events for the months October through April, averaged over the study period, for each of the three geographic regions (Sacramento, San Francisco, and Los Angeles). The strong effect of El Niño events on precipitation is evident. El Niño events changed the amount of precipitation, particularly in January and February, when San Francisco and Los Angeles experienced two to three times the normal amount of rain. Smaller increases in rainfall were noted in Sacramento. During El Niño events, Sacramento tended to be warmer (higher minimum temperature) during October and November and cooler in January through April. No consistent patterns were seen in minimum temperature or in temperature difference during El Niño events in San Francisco and Los Angeles.

Table 4 shows the number of hospitalizations for viral pneumonia and the 1990 Census population in the three regions. As expected, there were considerably more hospitalizations in Los Angeles with its larger population base. More viral pneumonia hospitalizations occurred in the youngest and oldest age groups compared to the mid-range group in all three geographic regions.

Figures 2 through 4 show precipitation, minimum temperatures, and hospitalizations for viral pneumonia in the three regions for July 1990 through December 1992. This period was chosen to show both a normal weather period and an El Niño event, and was representative of the entire study period. (Compressing the full record on one figure obscured the weather-hospitalization patterns.) The seasonality of viral pneumonia was clearly evident, particularly in Sacramento and Los Angeles (Figure 3), as was the increase in hospitalizations when minimum temperatures dropped. The decrease in minimum temperatures occurred before the increase in hospitalizations. Figure 4 shows a similar but less dramatic pattern for San Francisco, partly because minimum temperatures varied less.

Tables 5 through 7 show the change in number of viral pneumonia hospitalizations for each weather variable. The tables list the percent change and 95% confidence intervals for normal weather periods, El Niño events, and the comparisons of both mild and strong El Niño events with normal weather periods. There were two consistent findings across the three regions. First, there was little change in hospitalizations following increases in precipitation. Second, patterns of associations with temperature, precipitation, and SST tended to be similar during normal weather periods and El Niño events.

Table 3. Average weather data for October through April by normal and El Niño periods for Sacramento, San Francisco/San Mateo, and Los Angeles/Orange counties, 1983-1998

	October	November	December	January	February	March	April
Sacramento County							
Precipitation (inches)							
Normal	0.9	13.0	11.6	10.6	17.2	15.6	5.4
Mild El Niño	4.4	3.8	10.9	17.6	2.4	4.7	1.4
Severe El Niño	4.3	12.8	7.9	19.7	24.8	11.0	4.1
Minimum temperature (degrees C)							
Normal	44.5	38.8	38.9	43.3	44.2	47.3	51.9
Mild El Niño	50.8	42.1	37.3	39.3	42.6	46.0	48.4
Severe El Niño	52.3	44.4	38.3	39.3	42.9	45.0	47.7
Temperature difference (degrees C)							
Normal	30.4	19.7	14.6	17.2	18.8	21.1	25.7
Mild El Niño	26.7	24.0	16.8	14.0	21.2	24.7	28.9
Severe El Niño	27.7	20.3	15.9	13.0	17.2	21.1	24.9
San Francisco/San Mateo counties							
Precipitation (inches)							
Normal	0.8	14.0	11.9	10.9	16.9	16.6	4.7
Mild El Niño	5.9	6.0	13.2	16.4	3.7	4.3	1.3
Severe El Niño	4.5	15.7	9.7	25.6	26.7	11.4	4.9
Minimum temperature (degrees C)							
Normal	51.5	47.6	44.3	43.8	46.3	46.0	47.0
Mild El Niño	51.5	46.1	42.7	43.8	46.6	46.7	46.9
Severe El Niño	52.0	48.1	42.9	43.2	45.7	46.7	47.6
Temperature difference (degrees C)							
Normal	20.2	15.9	14.3	15.5	15.2	16.4	17.8
Mild El Niño	18.2	18.2	14.8	13.2	17.0	18.6	17.4
Severe El Niño	19.0	16.2	15.0	14.3	14.9	15.8	17.0
Los Angeles/Orange counties							
Precipitation (inches)							
Normal	1.3	6.8	4.2	5.1	17.7	11.5	4.3
Mild El Niño	3.1	1.0	7.9	17.7	5.8	0.7	0.9
Severe El Niño	1.4	8.5	7.1	18.3	22.8	12.0	3.1

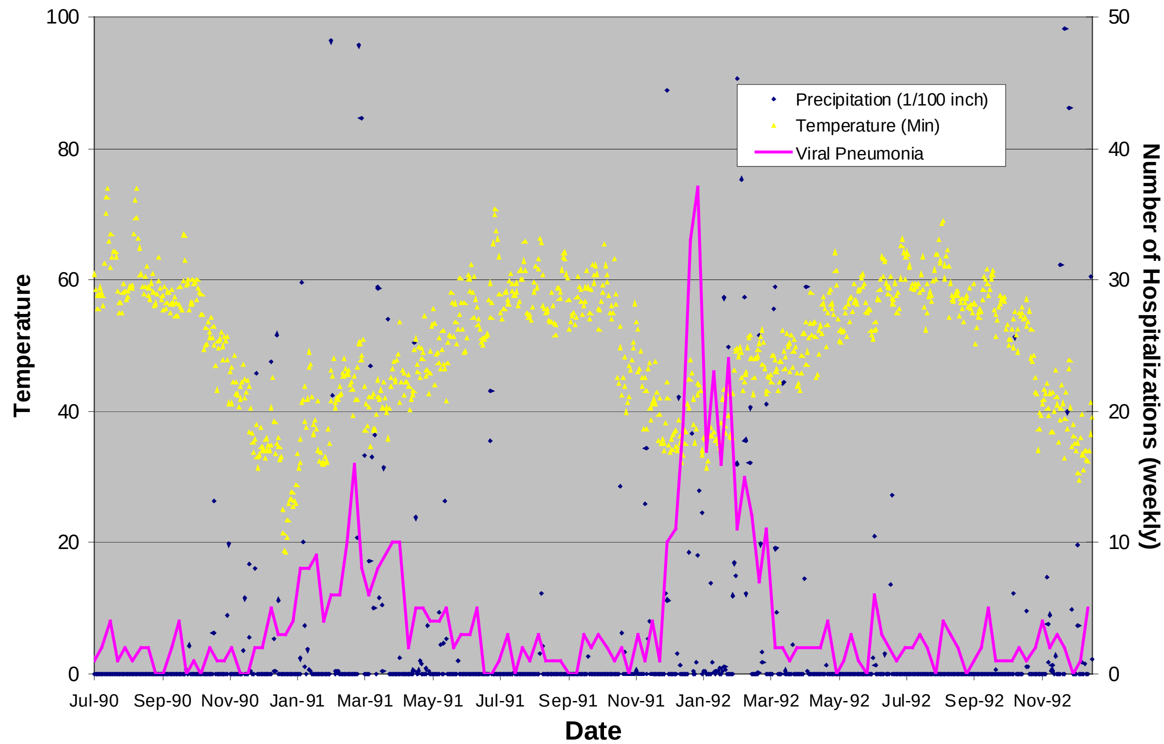
Table 3. Average weather data for October through April by normal and El Niño periods for Sacramento, San Francisco/San Mateo, and Los Angeles/Orange counties, 1983-1998 (cont.)

	October	November	December	January	February	March	April
Los Angeles/Orange counties (cont.)							
Minimum temperature (degrees C)							
Normal	56.5	48.6	44.3	47.2	46.8	50.2	54.6
Mild El Niño	55.1	47.8	43.4	47.3	47.6	51.0	54.6
Severe El Niño	56.2	49.1	44.8	46.0	47.8	50.5	55.7
Temperature difference (degrees C)							
Normal	23.0	21.3	23.2	23.2	20.3	21.0	21.2
Mild El Niño	21.6	24.6	21.9	19.6	23.3	24.4	22.0
Severe El Niño	22.8	22.9	21.6	20.9	19.4	20.2	21.7

Table 4. Number of hospital admissions for viral pneumonia and 1990 census population in Sacramento, San Francisco/San Mateo, and Los Angeles/Orange counties, females, 1983-1998

	Age at admission		
	0-17	**18-55**	**55+**
Viral pneumonia cases			
Sacramento	951	270	359
San Francisco/San Mateo	837	259	564
Los Angeles/Orange	3,743	2,571	3,656
Total population			
Sacramento	134,492	289,659	107,450
San Francisco/San Mateo	126,162	391,141	173,594
Los Angeles/Orange	1,420,913	3,136,123	1,081,226

In Sacramento (Table 5), a decrease of 5°F in the maximum temperature difference increased hospitalizations by more than 25% for both normal weather periods and El Niño events in all three age groups. Changes in the minimum temperatures were also associated with viral pneumonia hospitalizations, but the confidence intervals were wide and the associations were not consistent across age groups. During El Niño events, a 1°C decrease in SST was associated with a 14%-22% increase in hospitalizations. During normal weather periods, changes in SST were more strongly associated with hospitalizations in younger age groups; the oldest age group showed no association. Some of the variability was due to small numbers in particular cells, as evidenced by the wide confidence intervals.



Source: California Hospital Discharge Data (OSHPD), July 1990-1992

Figure 2. Minimum temperature precipitation and viral pneumonia, Sacramento area (Sacramento, Yolo counties), July 1990-1992

Source: Ebi et al., 2001.

Comparing El Niño events to normal weather periods in Sacramento, hospitalizations decreased for children by 21%-28% and increased for adults by 10%-48%. The associations were more pronounced during mild El Niño events.

The patterns of association were different in San Francisco (Table 6). In this region, minimum temperature was strongly associated with hospitalizations; decreasing the minimum temperature by 5°F increased viral pneumonia hospitalizations by more than 30% in all age groups during both types of weather. As was found in Sacramento, SST had a stronger association in the younger age group (25% increased hospitalizations during normal weather periods for a 1°C decrease in SST); no significant association was seen in adults. Maximum temperature difference was more important for adults (slightly decreased hospitalizations during normal weather periods, with increased hospitalizations during El Niño events). Viral pneumonia hospitalizations showed little change between normal weather periods and El Niño events.

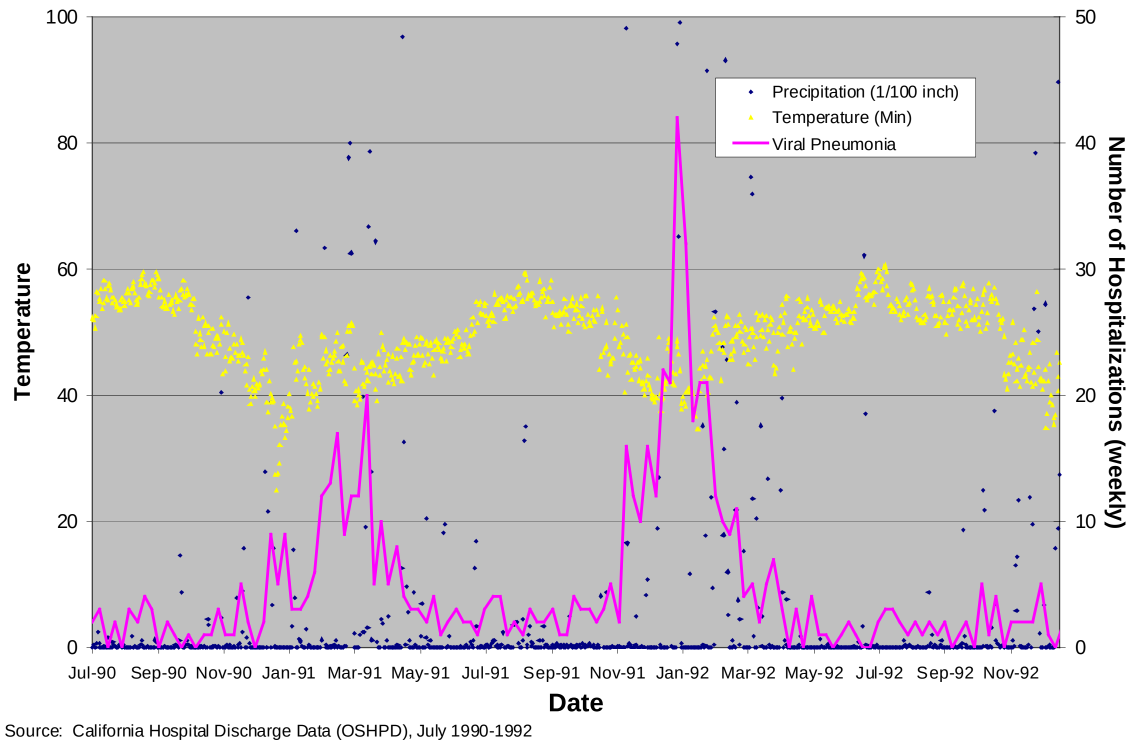


Figure 3. Minimum temperature precipitation and viral pneumonia, San Francisco area (San Francisco, San Mateo counties), July 1990-1992

Source: Ebi et al., 2001.

Similar patterns were found for Los Angeles (Table 7), with two exceptions. First, weather variables had a weaker association in Los Angeles than in San Francisco, although decreasing minimum temperature maintained a strong association with viral pneumonia hospitalizations. Second, the patterns for SST and maximum temperature difference were weaker and inconsistent in adults. As in San Francisco, El Niño events had little additional association with hospitalizations in Los Angeles.

4.2 Cardiovascular Diseases and Stroke

Table 8 lists the number of hospitalizations by county, disease, age, and gender. As expected, the number of hospitalizations was much larger for Los Angeles than for the other areas. The numbers also show the burden of these diseases (i.e., 397,438 hospitalizations for stroke in Los Angeles and Orange counties over 15.5 years).

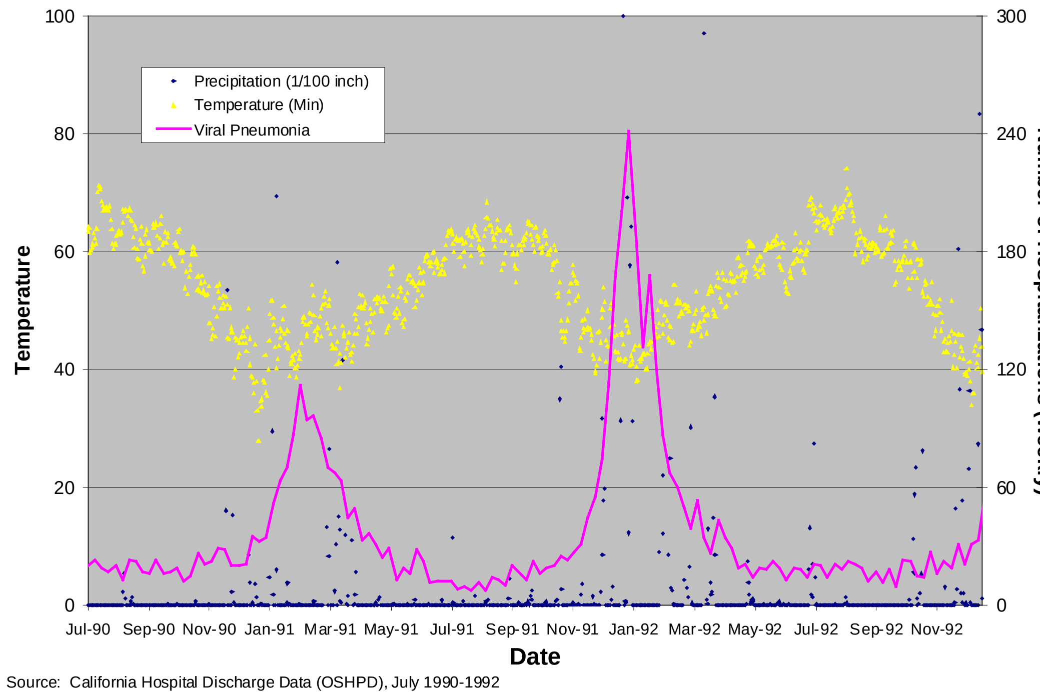


Figure 4. Minimum temperature precipitation and viral pneumonia, greater LA (Los Angeles, Orange counties), July 1990-1992

Source: Ebi et al., 2001.

The results are presented by geographic region, because admission patterns for the different diseases varied across the state (Tables 9-11). Each table gives the point estimates from the strata-specific analyses of normal weather periods, in addition to the estimates for the effect of El Niño periods from the analyses that included El Niño indicators in the model. Extremely hot days, precipitation, and SST were not associated with large differences in hospitalizations for any county/disease/age/gender analysis, and are not discussed further. The point estimates for extremely hot days are not included in the tables because they were never larger than ±0.2%. Table 12 is a summary of these results in changes in hospitalization.

In Los Angeles, a 3°C in maximum temperature was associated with small changes in hospitalizations, most of which were not statistically significant (Table 9). Among men, an increase in the minimum temperature decreased hospitalizations for angina by about 9% for those aged 70+, and decreased hospitalizations for congestive heart failure by about 5% in both 55-69 and 70+ age groups. Among women, an increase in the minimum temperature decreased hospitalizations for all age/disease categories except angina in younger women; the range of the point estimates was approximately 3%-8%.

Table 5. Percent change[a] and 95% confidence interval in viral pneumonia hospital admissions,[b] normal and El Niño seasons, females, 1983-1998 (Sacramento/Yolo counties)

Age group	**0-17**		**18-55**		**56+**	
Season	**Normal**	**El Niño**	**Normal**	**El Niño**	**Normal**	**El Niño**
Precipitation	2.2	-3.0	-7.6	-9.6	-3.8	-4.2
	(1.8, 2.6)	(-4.1, -2.0)	(-11.0, -4.0)	(-15.3, -3.5)	(-5.2, -2.3)	(-4.7, -3.8)
SST	30.7	15.4	11.3	14.4	-4.5	22.0
	(29.0, 32.4)	(11.8, 19.0)	(6.1, 16.8)	(9.5, 19.6)	(-9.5, 0.8)	(16.5, 27.6)
Temperature difference (degrees C)	26.4	28.1	41.9	48.3	30.8	37.2
	(19.0, 34.4)	(20.0, 36.8)	(36.9, 47.2)	(22.7, 79.3)	(1.9, 68.0)	(22.9, 53.2)
Minimum temperature (degrees C)	24.2	12.5	-0.6	-2.5	13.8	14.5
	(8.2, 42.5)	(3.9, 21.7)	(-12.7, 13.1)	(-3.8, -1.1)	(-14.5, 51.6)	(3.4, 26.7)
Mild El Niño versus normal[c]	-21.5		48.0		35.8	
	(-26.2, -16.4)		(38.6, 58.1)		(32.0, 39.7)	
Strong El Niño versus normal[c]	-28.3		10.3		14.5	
	(-28.6, -28.1)		(6.4, 14.4)		(-2.5, 34.5)	

a. Corresponding to change of: +0.2 inches for precipitation, -5° for temperature, -1° for SST.
b. Four day totals with a 7 day lag.
c. Adjusting for weather variables and year.

Table 6. Percent change[a] and 95% confidence interval in viral pneumonia hospital admissions,[b] normal and El Niño seasons, females, 1983-1998 (San Francisco/San Mateo counties)

Age group	0-17		18-55		56+	
Season	**Normal**	**El Niño**	**Normal**	**El Niño**	**Normal**	**El Niño**
Precipitation	1.5	1.2	3.5	0.3	0.3	-2.1
	(-1.8, 4.8)	(-1.6, 4.0)	(0.3, 6.8)	(-0.8, 1.4)	(-8.3, 9.7)	(-6.1, 2.2)
SST	24.6	17.4	6.7	8.2	5.6	13.5
	(9.9, 41.2)	(15.3, 19.5)	(-12.3, 29.8)	(0.3, 16.8)	(-4.3, 16.5)	(5.2, 22.4)
Temperature difference (degrees C)	0.0	10.5	-13.6	14.6	-6.9	20.8
	(-2.3, 2.3)	(-0.7, 23.0)	(-20.9, -5.6)	(4.2, 26.1)	(-24.4, 14.6)	(19.4, 22.3)
Minimum temperature (degrees C)	46.2	30.3	57.4	46.8	56.2	49.9
	(33.2, 60.3)	(25.5, 35.3)	(17.9, 110.1)	(46.1, 47.6)	(51.7, 60.9)	(35.7, 65.5)
Mild El Niño versus normal[c]	-1.9		2.3		25.7	
	(-32.6, 42.8)		(-7.4, 13.0)		(7.3, 47.3)	
Strong El Niño versus normal[c]	-10.5		5.4		4.9	
	(-17.5, -2.9)		(-21.9, 42.3)		(-12.5, 25.8)	

a. Corresponding to change of: +0.2 inches for precipitation, -5° for temperature, -1° for SST.
b. Four day totals with a 7 day lag.
c. Adjusting for weather variables and year.

Table 7. Percent change[a] and 95% confidence interval in viral pneumonia hospital admissions,[b] normal and El Niño seasons, females, 1983-1998 (LA/Orange counties)

Age group	**0-17**		**18-55**		**56+**	
Season	**Normal**	**El Niño**	**Normal**	**El Niño**	**Normal**	**El Niño**
Precipitation	1.0	0.0	2.3	0.9	-1.4	0.8
	(0.9, 1.1)	(-0.2, 0.3)	(2.3, 2.4)	(0.7, 1.1)	(-2.1, -0.7)	(-0.1, 1.7)
SST	21.6	8.5	-4.3	0.2	6.6	18.4
	(16.4, 27.1)	(7.9, 9.1)	(-14.8, 7.5)	(-0.0, 0.3)	(6.6, 6.6)	(16.2, 20.7)
Temperature difference (degrees C)	-1.3	-0.7	-2.9	-1.7	-10.5	0.5
	(-5.4, 2.9)	(-1.0, -0.5)	(-3.8, -2.0)	(-5.5, 2.3)	(-12.1, -8.8)	(0.4, 0.5)
Minimum temperature (degrees C)	30.4	18.4	31.9	30.9	31.7	16.5
	(23.9, 37.2)	(11.2, 26.0)	(19.4, 45.6)	(23.9, 38.2)	(30.6, 32.9)	(13.7, 19.4)
Mild El Niño versus normal[c]	-3.0		-4.6		1.3	
	(-4.4, -1.6)		(-6.6, -2.6)		(-1.6, 4.4)	
Strong El Niño versus normal[c]	-4.6		-4.2		-0.9	
	(-8.6, -0.5)		(-9.7, 1.6)		(-13.0, 12.9)	

a. Corresponding to change of: +0.2 inches for precipitation, -5° for temperature, -1° for SST.
b. Four day totals with a 7 day lag.
c. Adjusting for weather variables and year.

Table 8. Number of hospital admissions for selected diseases in Sacramento, San Francisco/San Mateo, and Los Angeles/Orange counties, 1983-1998

	Age at admission			
	Males		Females	
	55-69	70+	55-69	70+
Acute MI				
Los Angeles/Orange	67,401	61,920	29,825	63,738
San Francisco/San Mateo	9,341	10,649	4,067	10,766
Sacramento/Yolo	8,110	6,977	3,848	6,439
Angina				
Los Angeles/Orange	73,250	55,553	58,893	83,691
San Francisco/San Mateo	9,548	6,938	5,858	8,165
Sacramento/Yolo	10,427	6,424	5,999	6,578
Congestive heart failure				
Los Angeles/Orange	54,285	109,100	46,800	161,211
San Francisco/San Mateo	7,538	17,547	5,184	22,091
Sacramento/Yolo	5,570	10,252	4,315	13,544
Stroke				
Los Angeles/Orange	63,678	109,748	54,864	169,148
San Francisco/San Mateo	9,224	18,734	7,490	27,202
Sacramento/Yolo	6,688	11,463	5,679	15,240

The results from the Los Angeles strata-specific analyses of El Niño periods were similar, with the point estimates tending to be slightly smaller than those during normal weather periods (results not shown). In the model that included El Niño indicators, the point estimates for El Niño events were small or not statistically significant for men. Among women, the point estimates for El Niño periods were larger, but there was no consistent pattern between ages and between mild and strong El Niño events.

Changes in weather had a larger effect on hospitalizations in San Francisco (Table 10). For men and women 70+ years of age, changes in both maximum and minimum temperature were associated with significant changes in hospitalizations for all diseases; decreasing maximum temperature and increasing minimum temperature increased hospitalizations from 6% (angina in men) to 20% (acute MI in women). Changes in maximum and minimum temperature were also associated with large changes in hospitalizations for congestive heart failure among men and women 55-69 years old (approximately 19% change in hospitalizations for maximum temperature and 10%-20% for minimum temperature). Very similar results were found during El Niño periods (results not shown). In the model that included El Niño indicators, the estimates for El Niño events were statistically significant for both men and women for angina (a 13%-15% change in hospitalizations for men and an 8%-9% change in hospitalizations for women). There was no difference between mild and strong El Niño events.

Table 9. Los Angeles: Percent change[a] (95% confidence interval) in hospital admissions, 1983-1998[b]

	Acute MI		Angina		Congestive heart failure		Stroke	
Age	**55-69**	**70+**	**55-69**	**70+**	**55-69**	**70+**	**55-69**	**70+**
Males								
Precipitation	0.4	0.5	1.3	0.9	0.2	0.5	1.0	0.8
	(0.0, 0.8)	(0.4, 0.6)	(1.1, 1.4)	(0.7, 1.1)	(-0.1, 0.5)	(0.4, 0.7)	(0.4, 1.6)	(0.3, 1.3)
SST	-0.5	2.1	-1.7	-0.6	-0.1	0.8	-1.8	1.5
	(-3.8, 2.9)	(-0.1, 4.4)	(-2.7, -0.8)	(-1.3, 0.2)	(-0.9, 0.8)	(-0.2, 1.8)	(-3.6, 0.1)	(0.3, 2.6)
Maximum temperature (degrees C)	0.3	-0.4	1.5	-3.6	2.3	0.4	0.3	-1.1
	(-0.2, 0.9)	(-2.5, 1.7)	(-0.5, 3.5)	(-5.4, -1.7)	(-0.6, 5.3)	(-0.9, 1.7)	(-1.9, 2.6)	(-2.6, 0.3)
Minimum temperature (degrees C)	-2.0	0.1	-1.5	-8.6	-4.5	-5.7	-2.5	-1.9
	(-2.8, -1.2)	(-1.0, 1.2)	(-3.5, 0.5)	(-12.1, -5.0)	(-4.9, -4.1)	(-6.6, -4.8)	(-6.3, 1.4)	(-2.3, -1.4)
Mild El Niño	0.9	2.0	-2.0	-1.8	-1.1	-3.9	-4.8	-1.3
	(-1.9, 3.7)	(0.8, 3.3)	(-7.2, 3.5)	(-2.0, -1.6)	(-2.8, 0.7)	(-7.0, -0.6)	(-4.9, -4.7)	(-4.6, 2.2)
Strong El Niño	3.7	2.3	0.3	-1.0	-0.9	-4.6	-0.3	0.9
	(-1.6, 9.3)	(0.5, 4.0)	(-6.0, 7.0)	(-5.9, 4.1)	(-4.6, 3.0)	(-12.4, 3.9)	(-4.2, 3.7)	(-3.4, 5.3)
Females								
Precipitation	0.2	-0.3	-0.3	1.0	0.4	0.5	1.3	0.6
	(-0.0, 0.5)	(-0.7, 0.1)	(-0.9, 0.4)	(0.5, 1.5)	(-0.3, 1.1)	(0.1, 0.9)	(1.0, 1.6)	(0.4, 0.7)
SST	-1.0	-0.2	-1.9	-3.6	-0.2	3.7	-0.6	-0.9
	(-1.8, -0.3)	(-1.6, 1.3)	(-4.0, 0.2)	(-4.8, -2.4)	(-1.0, 0.6)	(3.5, 4.0)	(-2.0, 0.8)	(-1.9, 0.1)
Maximum temperature (degrees C)	-3.3	0.5	4.9	1.3	-1.5	1.1	-2.5	-0.9
	(-6.0, -0.5)	(-0.7, 1.6)	(3.9, 6.0)	(-0.5, 3.1)	(-2.7, -0.3)	(-0.5, 2.7)	(-3.9, -0.9)	(-1.6, -0.2)
Minimum temperature (degrees C)	-8.5	-3.6	-0.9	-5.5	-6.2	-2.9	-4.0	-4.0
	(-9.0, -8.0)	(-5.2, -2.0)	(-1.2, -0.6)	(-5.5, -5.4)	(-8.2, -4.2)	(-4.1, -1.7)	(-6.6, -1.3)	(-4.2, -3.9)
Mild El Niño	-2.3	2.9	-5.2	-6.5	-3.9	-2.7	-5.2	-0.7
	(-5.4, 1.0)	(1.5, 4.2)	(-7.1, -3.3)	(-6.6, -6.4)	(-5.9, -1.7)	(-4.7, -0.6)	(-6.8, -3.6)	(-0.8, -0.7)
Strong El Niño	-6.4	4.2	2.1	-3.2	1.9	-0.4	1.3	3.8
	(-10.0, -2.6)	(1.4, 7.1)	(-0.5, 4.8)	(-3.9, -2.6)	(-1.0, 5.0)	(-1.9, 1.1)	(-2.4, 5.2)	(2.5, 5.2)

a. Corresponding to change of: +0.2 inches for precipitation, -3°C for maximum temperature, +3°C for minimum temperature, -1°C for SST.
b. Four day totals with 7 day lag.

Table 10. San Francisco: Percent change[a] (95% confidence interval) in hospital admissions, 1983-1998[b]

	Acute MI		Angina		Congestive heart failure		Stroke	
Age	**55-69**	**70+**	**55-69**	**70+**	**55-69**	**70+**	**55-69**	**70+**
Males								
Precipitation	-0.7	-1.6	-1.2	-4.1	-3.2	-1.2	-0.9	-1.7
	(-0.1, -1.2)	(-2.5, -0.7)	(-3.7, 1.3)	(-7.7, -0.3)	(-5.2, -1.2)	(-2.4, -0.0)	(-1.1, -0.8)	(-1.7, -1.6)
SST	-2.4	1.6	3.0	2.5	1.6	2.2	0.0	-1.0
	(-0.0, -4.8)	(1.2, 2.0)	(0.5, 5.6)	(0.5, 4.5)	(-0.4, 3.6)	(-1.0, 5.6)	(-1.2, 1.1)	(-2.0, 0.1)
Maximum temperature (degrees C)	13.5	19.6	0.1	6.2	18.8	19.7	7.8	13.6
	(13.0, 14.0)	(15.1, 24.2)	(-3.6, 3.9)	(3.0, 9.5)	(10.9, 27.3)	(9.0, 31.3)	(5.3, 10.4)	(11.9, 15.4)
Minimum temperature (degrees C)	2.0	15.7	5.0	14.0	10.1	15.2	3.0	6.8
	(-1.0, 5.1)	(10.2, 21.4)	(1.7, 8.3)	(7.3, 21.2)	(9.3, 11.0)	(14.0, 16.5)	(2.7, 3.3)	(6.4, 7.3)
Mild El Niño	-0.3	-0.8	15.6	13.0	3.2	2.9	-2.1	3.9
	(-0.3, -0.4)	(-1.8, 0.3)	(15.2, 16.0)	(12.0, 14.1)	(0.4, 6.1)	(-2.1, 8.1)	(-3.2, -1.0)	(2.2, 5.6)
Strong El Niño	-4.5	-2.6	14.6	13.5	-2.6	2.3	-5.1	4.1
	(-5.6, -3.4)	(-6.4, 1.3)	(9.5, 20.0)	(8.3, 18.9)	(-2.7, -2.5)	(-4.4, 9.5)	(-9.7, -0.4)	(1.2, 7.1)
Females								
Precipitation	-1.2	-1.2	-2.3	-1.7	-3.6	-1.1	0.7	-1.6
	(-3.1, 0.8)	(-3.8, 1.6)	(-2.6, -2.0)	(-3.9, 0.7)	(-5.8, -1.4)	(-21, -0.1)	(0.2, 1.2)	(-1.8, -1.5)
SST	1.7	1.9	4.9	1.0	1.9	2.8	3.0	-0.3
	(-2.3, 5.8)	(-1.5, 5.4)	(4.3, 5.5)	(-0.6, 2.6)	(-2.7, 6.7)	(2.7, 2.9)	(1.5, 4.4)	(-3.5, 3.1)
Maximum temperature (degrees C)	2.1	20.7	1.0	10.0	19.7	11.9	2.5	11.6
	(0.6, 3.7)	(10.8, 31.4)	(-3.3, 5.4)	(9.7, 10.3)	(8.8, 31.8)	(7.7, 16.3)	(0.6, 4.3)	(9.2, 14.1)
Minimum temperature (degrees C)	0.8	19.5	9.3	12.3	16.1	8.6	10.0	10.8
	(-7.4, 9.7)	(13.1, 26.2)	(6.0, 12.8)	(11.1, 13.5)	(11.2, 21.1)	(5.9, 11.3)	(6.6, 13.6)	(10.3, 11.2)
Mild El Niño	-4.2	-5.1	9.5	8.1	-2.4	4.1	-3.8	-1.2
	(-4.9, -3.4)	(-8.4, -1.6)	(9.1, 9.9)	(8.0, 8.3)	(-5.1, 0.4)	(0.0, 8.4)	(-4.3, -3.4)	(-1.4, -0.9)
Strong El Niño	1.9	-6.8	9.3	8.4	-2.0	-1.0	-4.5	-0.5
	(0.7, 3.2)	(-8.1, -5.4)	(6.5, 12.2)	(7.7, 9.1)	(-6.2, 2.3)	(-2.2, 0.2)	(-7.5, -1.4)	(-2.3, 1.3)

a. Corresponding to change of: +0.2 inches for precipitation, -3°C for maximum temperature, +3°C for minimum temperature, -1°C for SST.
b. Four –day totals with 7 day lag.

Table 11. Sacramento: Percent change[a] (95% confidence interval) in hospital admissions, 1983-1998[b]

	Acute MI		Angina		Congestive heart failure		Stroke	
Age	**55-69**	**70+**	**55-69**	**70+**	**55-69**	**70+**	**55-69**	**70+**
Males								
Precipitation	0.8	-1.9	-0.3	0.7	1.5	0.6	0.5	-1.5
	(-0.4, 2.0)	(-4.6, 1.0)	(-0.4, -0.1)	(0.3, 1.1)	(1.3, 1.7)	(-1.4, 2.6)	(-0.1, 1.1)	(-2.1, -0.9)
SST	2.1	-2.3	-1.5	-1.9	6.1	1.4	0.9	-2.2
	(1.4, 2.9)	(-4.5, -0.1)	(-3.8, 0.7)	(-4.4, 0.7)	(4.1, 8.0)	(1.3, 1.6)	(0.3, 1.5)	(-3.4, -1.0)
Maximum temperature (degrees C)	2.4	6.3	6.5	-1.6	2.5	7.9	2.4	7.4
	(-2.8, 7.8)	(2.4, 10.3)	(5.0, 8.1)	(-7.0, 4.2)	(-0.8, 6.0)	(2.1, 14.0)	(0.5, 4.3)	(5.5, 9.3)
Minimum temperature (degrees C)	5.8	7.1	6.5	-6.3	4.8	4.8	2.0	13.1
	(-5.9, 18.9)	(6.5, 7.8)	(1.0, 12.2)	(-11.7, -0.5)	(-3.4, 13.7)	(-2.4, 12.5)	(-5.1, 9.7)	(10.0, 16.2)
Mild El Niño	4.3	-1.0	-4.5	-7.2	-0.3	-5.0	-8.1	-2.9
	(2.7, 6.0)	(-3.8, 1.9)	(-5.7, -3.4)	(-8.0, -6.4)	(-4.3, 3.8)	(-6.3, -3.8)	(-8.5, -7.7)	(-5.0, -0.8)
Strong El Niño	3.4	0.3	1.8	2.4	5.9	-2.5	-2.3	-5.6
	(-6.2, 14.0)	(-2.0, 2.6)	(-1.0, 4.6)	(0.3, 4.6)	(0.6, 11.4)	(-4.9, -0.1)	(-2.7, -1.9)	(-11.8, 0.9)
Females								
Precipitation	-2.9	-0.8	-0.7	1.0	-1.9	-2.0	-2.8	-0.4
	(-5.9, 0.2)	(-1.0, -0.6)	(-0.7, -0.6)	(0.2, 1.9)	(-2.9, -1.0)	(-2.9, -1.1)	(-3.4, -2.2)	(-1.5, 0.6)
SST	-1.0	-3.5	0.8	3.7	3.4	1.6	1.2	-3.0
	(-1.6, -0.5)	(-6.5, -0.4)	(-0.5, 2.2)	(-2.3, 10.0)	(3.4, 3.4)	(1.0, 2.3)	(0.8, 1.6)	(-4.2, -1.7)
Maximum temperature (degrees C)	19.2	10.7	3.8	1.6	4.3	11.4	15.4	2.8
	(2.7, 38.3)	(7.6, 13.7)	(3.2, 4.3)	(-2.5, 5.8)	(-1.4, 10.3)	(8.7, 14.3)	(12.2, 18.7)	(1.7, 3.9)
Minimum temperature (degrees C)	28.2	9.9	7.7	4.1	8.1	7.5	25.5	2.8
	(-3.1, 69.5)	(4.0, 16.1)	(-0.9, 17.1)	(0.2, 8.2)	(5.0, 11.1)	(5.9, 9.1)	(20.6, 30.6)	(2.0, 3.6)
Mild El Niño	5.1	13.5	-2.3	-2.0	3.5	0.3	10.5	3.1
	(3.1, 7.0)	(11.4, 15.6)	(-7.7, 3.5)	(-7.9, 4.3)	(3.0, 3.9)	(-2.2, 2.9)	(6.8, 14.4)	(-1.1, 7.4)
Strong El Niño	5.7	14.7	16.8	16.6	2.7	8.3	3.2	-3.6
	(3.4, 8.2)	(12.9, 16.6)	(7.4, 27.1)	(14.6, 18.7)	(1.6, 3.7)	(1.6, 15.5)	(2.9, 3.6)	(-10.4, 3.6)

a. Corresponding to change of: +0.2 inches for precipitation, -3°C for maximum temperature, +3°C for minimum temperature, -1°C for SST.
b. Four day totals with 7 day lag.

Table 12. Summary of changes in hospitalizations, 1983-1998

	Maximum temperature		Minimum temperature		El Niño events	
	Males	**Females**	**Males**	**Females**	**Males**	**Females**
Los Angeles						
Acute MI	_	_	_	↓	_	_
Angina	_	_ (55–69)	↓ (70+)	↓	_	↓ (70+)
Congestive heart failure	_	_	↓	↓	_	_
Stroke	_	↓	↓	↓	_	_
San Francisco						
Acute MI	_ _	_ _ (70+)	_ _ (70+)	_ _ (70+)	_	↓ (70+)
Angina	_	_ (70+)	_ _ (70+)[a]	_ _ (70+)[a]	_ _	_
Congestive heart failure	_ _	_ _	_ _	_ _ (55–69)[b]	_	_
Stroke	_ _	_ _ (70+)[a]	_	_ _	_ (70+)	↓ (55–69)
Sacramento						
Acute MI	_ (70+)	_ _	_ (70+)	_	_	_ _ (70+)[a]
Angina	_	_ (55–69))	_	_	_	_ _[c]
Congestive heart failure	_ (70+)	_ _ (70+)	_	_	↓ (70+)	_
Stroke	_	_ _ (55–69)[b]	_ _ (70+)	_ _ (55–69)[b]	↓	_

a. _ (55–69).
b. _ (70+).
c. Strong.

The Sacramento region exhibited patterns similar to those observed in San Francisco, but with weaker associations (Table 11). As in San Francisco, decreasing maximum and increasing minimum temperatures were associated with changes in hospitalizations. For men and women 70+ years of age, both changes in maximum and minimum temperature increased hospitalizations for acute MI and congestive heart failure (point estimates ranged from 6% to 11%). Among men 70+ years of age, changes in these weather variables also changed hospitalizations for stroke (7%-13%). A similar association was observed for women 55-69 years old, but was much weaker in the older age group. Changes in maximum and minimum temperature also were associated with increased hospitalizations for angina among men and women 55-69 years old (4%-8%), but not for the older age group.

In Sacramento, we observed broadly similar patterns during El Niño events (results not shown). In the model that included El Niño indicators, the estimates for El Niño events slightly decreased hospitalizations for men for a few age and disease categories, but the confidence intervals were wide and no clear pattern emerged between mild and strong events. Among women, El Niño events increased hospitalizations by 5%-14% for acute MI (14%-15% for ages 70+) and by 16% for angina (only for strong events).

5. Interpretation of Findings

5.1 Viral Pneumonia

Viral pneumonia hospitalizations showed the expected seasonal pattern (Kilbourne, 1987). With the exception of precipitation and SST, associations between viral pneumonia hospitalizations and specific weather variables varied by geographic region. In the study, the lack of association between precipitation and hospitalizations was interesting because precipitation, rather than changes in temperature, is more likely to drive Californians indoors where viral transmission is expected to occur (Kilbourne, 1987; Hope-Simpson, 1992). Decreased SSTs, used as a marker for weather effects other than those analyzed, was associated with increased hospitalizations in the youngest age group during normal weather periods in all three regions. This association was weaker during El Niño events. It would be interesting to understand which weather factors captured by this variable are important for predicting hospitalization patterns.

One temperature variable could not describe the hospitalization patterns found in the three geographic regions. In San Francisco and Los Angeles, a 5°F decrease in the minimum temperature was associated with a large increase in hospitalizations (about 30%-50%). In Sacramento, a 5°F decrease in the maximum temperature difference was associated with a large increase in hospitalizations (about 25-40%). There appeared to be no association between El Niño events and hospitalizations in San Francisco and Los Angeles, possibly because temperatures did not change much in these regions during El Niño events. In Sacramento, where seasonal temperatures changed during El Niño events, viral pneumonia hospitalizations decreased in children and increased in adults. There is no obvious explanation for these patterns. Further investigation is required to understand the differences among the age groups in terms of changes in behavior, potential exposures, and other factors during El Niño events and normal weather periods. The recently developed ability of climatologists to predict El Niño events would permit public health interventions to be instituted once these differences are understood.

More analyses are required to understand the relative importance of weather variables and specific weather patterns in the context of other factors associated with virus transmission (Hope-Simpson, 1992). Because no data were available on viral isolates, it was impossible to determine whether patterns varied by virus type. Nor were data available on air pollution. Air pollution exposures could confound these weather-hospitalization associations, but it is unclear in which direction. For example, the increased precipitation during El Niño events may result in decreased exposure to some air pollutants. Much of the literature on air pollution and respiratory diseases has treated weather as a confounding variable to be controlled in the analysis. Further analysis is warranted to understand the joint and separate associations of weather variables and air pollution with hospitalizations for viral pneumonia. Such analyses should take El Niño events into account where appropriate.

These data underscore the difficulties in assessing the potential health effects of climate variability and change. The associations between viral pneumonia hospitalizations and specific weather factors varied across the geographic regions. A model based on either the inland region or one of the coastal regions would not be predictive of the other regions.

There is interest in predicting how trends in winter influenza mortality could change with warmer winters (McMichael et al., 1996; Patz et al., 2000). In this context, it is important to note that social and economic factors — in addition to weather — can influence disease patterns. However, to inform decision makers and to prioritize research areas, considering what would happen if only weather changed can be useful. In that unlikely scenario, if the weather-viral pneumonia hospitalization pattern in Sacramento resembles that in regions with colder climates, the results from El Niño events suggest that warmer winters may be associated with fewer hospitalizations in children and more hospitalizations in adults. El Niño events are short-term weather fluctuations, and the response of a population to these events may be different from an acclimated response to long-term climate change. Different patterns could lead to different conclusions.

Although El Niño events were not associated with viral pneumonia hospitalizations in San Francisco and Los Angeles (regions with moderate climates), hospitalizations were associated with minimum temperature changes during both normal weather periods and El Niño events. These results do not directly address the question of whether warmer global temperatures could reduce winter influenza mortality. However, they do suggest that viral pneumonia would likely continue to have a seasonal pattern, showing a significant association with hospitalizations, even as cities in colder climates begin to experience warmer temperatures.

5.2 Cardiovascular Diseases and Stroke

The patterns of association between weather variables and hospitalizations for acute MI, angina, congestive heart failure, and stroke varied by geographic region, age, and gender. All diseases were associated with at least one weather variable in at least one age, gender, and geographic region. Within a geographic region, if hospitalizations were associated with temperature, several of the studied diseases were associated with these changes. We analyzed the temperature data using 3°C decreases in maximum temperature and 3°C increases in minimum temperature. Under most circumstances, these changes would mean colder days and warmer nights, respectively, between 4 day periods. If these variables had been entered into the analysis as a 3°C increase in maximum temperature (warmer days) and a 3°C decrease in minimum temperature (colder nights), the results would have been in the opposite direction to those reported; the point estimates would have been of similar overall magnitude, but in the opposite direction. Because the analyses were conducted using a 7 day lag, the patterns observed could be used by hospitals to plan staff utilization and bed allocation.

Maximum and minimum temperature showed the strongest correlations with disease; changes in the other weather variables had a much smaller or negligible effect on hospitalizations. Extremely hot days and precipitation had little effect. In certain analyses, SST was associated with hospitalizations, but the associations were smaller than those observed for temperature. SST was used as a marker for weather variables not explicitly included in the analysis, which suggests that other weather variables may be contributing to the reasons for hospitalization.

Although the weather-disease associations were weakest in Los Angeles, even a 5% change in hospitalizations for these common diseases represents a large number of hospitalizations. Associations with weather were moderately strong in Sacramento and strongest in San Francisco, where large changes in hospitalizations (up to 20%) were observed for colder days and warmer nights, particularly for acute MI for ages 70+ and for congestive heart failure for ages 55+.

There are few studies with which to compare these results. One similar study is a 10 year population-based survey on the occurrence of MI and coronary deaths in males in a region of northern France (Danet et al., 1999). However, the data are not fully comparable because our study does not include disease incidence data. Hospitalizations represent patients with disease severe enough to require medical attention who have survived long enough to be admitted to hospitals. Moreover, it could not be ascertained whether a hospitalization was a first or subsequent occurrence. Danet et al. (1999) found that a 10°C decrease in average daily temperature was associated with a 13% increase in fatal, incident, and recurrent coronary events in males. The association was strongest (18%) in the oldest age group studied (55-64 years) and for recurrent events (26% increase). The magnitude of the changes in hospitalizations in Sacramento and San Francisco is similar, although temperature was analyzed differently in the two studies.

The findings of this investigation are similar to some of the results reported by McGregor for Birmingham, U.K. (McGregor, 1999). McGregor investigated the association between weather and winter ischemic heart disease deaths. One major difference between the analyses is that McGregor used a synoptic climatological approach. McGregor's results showed statistically significant relationships between mortality and two types of air masses (a cold polar continental air mass and a moderately warm, blustery maritime air mass), with evidence suggestive of a threshold effect. McGregor also found that the persistence of certain air mass types was associated with increased mortality. It appeared that increases in ischemic heart disease mortality were associated with concurrent meteorological conditions and with antecedent and rapidly changing conditions in his study. The latter result is analogous to what we found here for San Francisco and Sacramento. It could be informative to re-analyze the California data using a synoptic approach to compare and contrast the results between the two countries. Although a synoptic approach may be more informative of actual weather conditions, it is more complicated to determine than to measure temperature or precipitation. For example, McGregor used meteorological data for seven variables in conjunction with principal component analysis, followed by cluster analysis, to determine winter air masses. Because of the complexity of this calculation, synoptic categories are not as easy for most people to understand as temperature and precipitation.

Feigin et al. (2000) found that the risk of ischemic stroke occurrence was 32% higher on days with low ambient versus high ambient temperature, and that the risk of intracerebral hemorrhage was 52% higher on days with mild versus high ambient temperature in Siberia, Russia. Although the temperature ranges are much different between Siberia and the San Francisco and Sacramento regions, the patterns between these areas are similar in that stroke increased with decreasing maximum temperature. This consistency further shows that weather is contextual within a population, and that acclimatization occurs in response to long-term climate change. This consistency also supports the hypothesis that changes in the weather appear to be important in the occurrence of stroke. Further analyses should consider stroke subtypes.

It is interesting to speculate about why the associations vary among the different regions in California. In Los Angeles, no consistent patterns in hospitalizations emerged after a decrease in the maximum temperature. Hospitalizations decreased for all diseases for females, and for all diseases other than acute MI for males, after an increase in minimum temperature. These results may be due to the warmer weather in Los Angeles. Tanaka et al. (2000) found lower mortality for ischemic heart disease and cerebrovascular disease in a warmer versus a cooler region of Japan. The investigation showed that even a relatively small seasonal change in temperature had a significant effect on mortality. Similar patterns have been reported elsewhere (Ku et al., 1998). It may be that less acclimatization and insulation from outdoor temperature is needed in regions with narrower annual temperature ranges.

The weather associations were strongest in San Francisco, where either a decrease in the maximum temperature or an increase in the minimum temperature was strongly associated with hospitalizations for all diseases in both males and females, particularly in the 70+ age group. One possible explanation may be that fewer San Francisco residents have access to temperature-controlled environments than do residents of Los Angeles or Sacramento. A corollary of this possibility is that fewer San Francisco residents use furnaces or air-conditioners when temperatures change suddenly. For example, although San Francisco is well known for episodes of summer fog resulting in colder than expected weather, furnaces may not be used on these cold days. San Francisco residents may also be less likely to use air-conditioning on the comparatively few hot days. This possibility is consistent with the suggestion that diminishing seasonal patterns of cardiovascular disease may result from the expansion of adequate heating systems and increased use of air conditioning (Seretakis et al., 1997; Lerchl, 1998; Kloner et al., 1999). The Eurowinter Group (1997) found direct associations between mortality from ischemic heart disease and cerebrovascular disease and protective measures against the cold and cooler homes. Of particular relevance was the fact that mortality was higher in regions with warmer winters. In addition, more middle-aged and elderly people in warmer countries failed to wear protective clothing in cold weather. Although that study focused on protective measures at 7°C and the results reported here generally apply to higher temperatures, taken together these results support the suggestion that protective measures may be of more value than the population perceives.

In Sacramento, the weather associations for males were evident, although weaker than in San Francisco; only angina failed to show any association. For females, similar patterns were evident in both Sacramento and San Francisco, but with stronger associations in Sacramento for changes in maximum, as opposed to minimum, temperature. For both regions, it is clear that specific changes in temperature, particularly warmer nights, can lead to a large increase in hospitalizations.

The other consistent pattern in Sacramento and San Francisco is that weather-health associations, when present, tended to be stronger in the oldest age group. It has been shown that, with increasing age, people have progressively reduced physiological ability to sense changes in body temperature and to take appropriate actions (i.e., shiver or sweat) to regulate temperature (Bull and Morton, 1978).

The consistency of the results across disease categories suggests some common mechanism for physiological responses to changes in the weather. Seasonal and temperature variations have been described for blood pressure, blood viscosity, vasoconstriction, serum lipids, fibrinogen levels, and other blood components (Keatinge et al., 1984; Woodhouse et al., 1994; Yeh et al., 1996; Donaldson et al., 1997). Changes in some of these physiological factors are associated with morbidity and mortality from cardiovascular disease and stroke. For example, cold weather is associated with increases in systolic blood pressure, central blood volume, and haemoconcentration. Also, Curson (1996) suggested that physiological and biochemical processes occur in response to the passage of weather fronts and the attendant rapid meteorological changes. For example, changes in blood viscosity and clotting time occurred with the passage of major fronts. Our results suggest that physiological reactions to changes in temperature may depend, to some degree, on the preceding temperatures, and that the direction of change is important.

The results reported here represent the first analyses of the association of hospitalizations for cardiovascular diseases and stroke with El Niño events. El Niño events were associated with increased hospitalizations for angina in San Francisco and Sacramento (for females only), but with decreased hospitalizations in Los Angeles. In addition, in Sacramento El Niño events were associated with increased hospitalizations for acute MI and congestive heart failure among females, and with decreased hospitalizations for congestive heart failure and stroke among males. During El Niño winters, Sacramento tends to be warmer (higher minimum temperature) during October and November and cooler in January through April. No consistent patterns for temperature are evident for San Francisco and Los Angeles during El Niño events, but those cities can experience two to three times the normal amount of rainfall. Such changes in temperature and precipitation may be associated with behavioral changes that, in turn, exacerbate risk of hospitalization. Further understanding of these associations in conjunction with improved long-range forecasting accuracy of El Niño events can enable society to develop appropriate public health responses.

The analyses did not control for air pollution or for other risk factors associated with hospital admissions for heart disease. Air pollution is known to be associated with cardiovascular diseases. However, several studies have shown little or no association between weather and air pollutants, such as particulates (Samet et al.,1998; Zanobetti et al., 2000; Hales et al., 2001), carbon monoxide (Morris et al., 1995), and sulfur dioxide (Samet et al., 1998). This suggests that additional analyses that included data on air pollution would likely find point estimates similar to those reported here.

6. Summary

Although it is impossible to change the weather, understanding why specific weather factors are correlated with increased or decreased hospitalizations can lead to improved understanding of disease patterns. Vulnerability is a function of the sensitivity of a population to climate change and its ability to adapt in anticipation of or in response to adverse impacts (Smit and Pilifosova, 2001). A key public health goal is to reduce a population's vulnerability to the potential adverse consequences of climate variability and change, either by minimizing a population's risk of disease or by maximizing its adaptive capacity. These research findings are an important step in understanding population sensitivity under different weather conditions.

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